The Occurrence and Origin of Sand Bodies in Till, with Special Reference to the Franklin County, Ohio, Landfill Site[1]

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Abstract. **Many landfill siting reports, of which those of the Franklin County, OH, landfill are typical, imply continuity of minor sand bodies in till between widely-spaced test holes where sand deposits fall within similar depth ranges. This review of studies of the local origin of most sand and gravel "lenses" or "seams," and their transport in active glaciers, however, indicate that most such deposits probably have limited lateral continuity. Their role in the groundwater circulatory system is commonly exaggerated in landfill reports.**

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INTRODUCTION

This report was prepared originally as an internal report to Metcalf & Eddy, Inc., as an outgrowth of reviews of reports on the Franklin County Landfill site made for the Solid Waste Authority of Central Ohio. The landfill site is in southern Franklin County, about 10 miles south of Columbus, in a fairly representative part of the generally flat till plain that extends over most of west central Ohio and into eastern Indiana. In the original investigation of the site (Zande 1981) the glacial stratigraphy was defined on the basis of sand interbeds in the till matrix occurring within arbitrarily designated zones or ranges in elevation. From top down, the A zone included sand beds between elevations 861 and 842 feet (MSL), or about 7 to 14 feet below ground surface. Zones B1 and B2, separated in some borings by up to 12 feet of till, included sand beds between 857 and 812 feet (MSL) in elevation, or 8 to 41 feet below ground surface. Zones C1 and C2 included sand beds between elevations 823 and 788 feet (MSL) or 28 to 90 feet below ground surface.

All of the sand beds in zones A, B, and C were shown to be discontinuous in test drilling, and none of the beds were considered regional aquifers. The identified regional aquifer system is the so-called D-R zone, which includes basal sand and gravel deposits generally occurring beneath the C zone and in close association with, or directly overlying, the limestone bedrock.

The Franklin County Landfill site was approved and the landfill has been operating since about 1985. Some of the shallower sands were removed during construction of the cells and others were not considered important as potential fluid migration routes.

To provide for future expansion of the landfill, adjoining property was acquired and an investigation made of the glacial stratigraphy, chiefly to define the extent and depths of the sand interbeds, using the same arbitrary zoning as that at the original site. Thus, the A, B1, B2, C1, and C2 designations, with suitable adjustments for differences in elevation, were assigned to those sand and gravel "lenses," "stringers," and other stratified bodies, that occur in the new areas in the upper several feet of the till matrix.

This arbitrary classification, or grouping into specific ranges of elevations and depths of sand interbeds, has led investigators to attempt correlation of deposits over large distances simply because they may occur in widely-spaced test holes at roughly the same elevation. When shown in cross-sections it is implied that if intervening test wells were drilled, they would also show similar sand sections at appropriate depths. An impression is given that many, perhaps most, of these shallow sand beds are continuous over large areas and, therefore, they can act as permeable conduits that might conceivably transmit contaminants from a landfill to a distant well.

The purpose of this report is to show that most sand bodies in the upper part of the glacial till are of limited extent. Conclusions are based on reports of studies of outcrops and test borings and studies by glaciologists on the genesis of glacial deposits, including their observations in active glaciers. These studies indicate the discontinuous nature and limited extent of most sand interbeds in the surficial till. Such deposits are of course, in contrast to the more extensive, and thicker, outwash sand and gravel deposits, typically formed at the base, and in front, of a wasting glacier.

MATERIALS AND METHODS

In preparing this report, more than a score of texts and technical papers on glacial geology, acquired from the Polar Studies and Geology libraries at The Ohio State University and from private collections of glacial literature, were studied. These references, cited or quoted herein, will show that most shallow sand interbeds are unlikely to be of large areal extent, and should not be shown as implied continuous strata between test holes, where such test holes are more than a few feet, or a few tens of feet apart.

RESULTS

The ubiquity of sand interbeds in till was noted by Goldthwait (1971) who states:

> "Nearly every drill hole or large cut in till exposes some inclusion of well-sorted clay or silt, or bedded

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sand, or a lens of gravel. Correlation (of these deposits) from exposure to exposure, or from drill hole to drill hole and outcrop to outcrop is the big problem..."

Turning now to the mechanisms of deposition, Drewry (1986) states:

> "Sediments deposited from meltwater flowing in glacial channels of one sort or another accumulate in a highly unstable environment. Deposits may be rapidly modified by various external factors resulting in a spectrum of change from minor alteration of bedforms through loss of primary structures... to complete obliteration by erosion... Deposits (in ice tunnels) may be re-entrained the following spring and summer once passages and conduits are reoccupied and reamed-out as water discharge rises... These factors suggest that good preservation or survival of sediment bodies is likely only when the accumulation is small in size and located in the thinner marginal parts of ice masses where forward motion is small or the ice stagnant, tunnel closure rates are low, and the ice front is retreating...."

Stratified deposits result from debris-carrying meltwaters pouring into crevasses or moulins (deep vertical shafts in the glacier), leaving deposits which are ultimately incorporated into the till when the glacier melts. The mechanisms by which the debris load migrates upward into the ice is not altogether clear. Goldthwait (1971, p 9) states, "Arguments have developed over twenty years concerning just how coarse dirt is raised up into the ice." There is ample evidence in the form of surficial sand, gravel, and boulders, especially in end moraines, of persistent upward movement from the ground. The source of glacial meltwater is chiefly from melting at the surface (Shreve 1972). The annual discharge of meltwater varies enormously and a large proportion of the annual sediment load may be discharged in only a few days of higher summer flow. Observations indicate that from the Nisqually glacier in Washington the sediment transported during five minutes in June was equal to the total sediment yield for January (Drewry 1986, p 148).

Highly fluctuating meltwater and sediment sources, and the ever changing shapes and sizes of the openings in which the sediments accumulate produce a wide variety of englacial deposits. Subsequent deformation and displacement caused by the shifting and settling of the enclosing till as the glaciers melt result in a complicated assemblage of stratified deposits of such random shape and occurrence as to make them virtually impossible to correlate from drill hole to drill hole with any degree of confidence. Shreve (1972, p 206) states as follows:

> "considering the multitude of orientations and interconnections...typical temperate glacier ice almost certainly is at least slightly permeable to the flow of water. If so, then, taking account also of the larger passages through the ice, such as moulins and glacier tunnels, water can move through a glacier in a manner somewhat analogous to the movement of ground water through permeable cavernous limestone. Ice is far more deformable than limestone, however, so that passages in it can expand and contract significantly in response to the normal increases and decreases in water pressure on their walls... Thus, the behavior of the water passages is primarily the result of three basic characteristics: (1) the capacity of the system of passages to continually adjust, though not instantly, to increases or decreases in the supply of melt water; (2) in a steady state, the pressure, and hence the movement, of water in them is governed primarily by the ambient pressure in the enclosing ice and secondarily by the rate of melting of the passage walls; and, most important, (3) because of the differential growth of the larger passages, the network of passages tends in time to become arborescent, with tributaries forming into ever-larger trunk passages like a three-dimensional river network."

Shreve's description of the way water circulates and deposits are formed within glacial ice, with vertical and horizontal orientation, constantly acted upon by movement of the ice and finally let down piecemeal to their present positions within the till matrix when the ice melts, helps explain the difficulty in tracing very far the fragments of these deposits which we commonly refer to as "lenses" in the till.

An illustration of the complex occurrence of sand bodies in till is given by Savage and Lowell (1992) in describing a till exposure near Cincinnati. They refer to:

> "numerous annular, lenticular, and convoluted bodies of sand, silt, clay, and gravel within the diamicton (till).... Their orientation may be vertical, horizontal, or dipping...their transport and deposition probably occurred while the blocks were still frozen... These characteristics are consistent with deposition associated with inactive ice, and represent a transition from active, melting ice to inactive (or stagnant) melting ice."

If one considers the fact that during the late Wisconsinan alone, central Ohio was covered by an estimated 3000 feet of glacial ice (Goldthwait 1959, p 200), subject in its approximately 7000 years of existence to climatic fluctuation with melting, refreezing, advances and retreats, and a long dissolution history of final melting and disappearance from the area about 16,000 years ago, some idea can be gained of the complicated genesis of the deposits the glacier left behind.

The forgoing description and comment is not to imply that all stratified glacial deposits are of local and limited extent. Some englacial deposits have fairly large lateral continuity, such as eskers (long sinuous ridges of sand and gravel formed in crevasses or ice tunnels). Some of the sand and gravel deposits at a given site may be eskers, and some may be fairly long, but tracing them individually would be difficult without extensive test drilling. On the outcrop eskers are characterized by high dip angles of crossbeds and other factors (Jurgaitis and Juozopavicius 1988), but they would be next to impossible to identify from test hole samples. Eskers may be oriented perpendicular or transverse to the direction of ice movement (Sugden and John 1976), so the assumed directional movement of the ice is of no help in determining whether a given deposit may or may not be part of an esker.

Another major type of stratified glacial deposit, commonly referred to as outwash, is formed in front of a wasting glacier by meltwater streams. Outwash is typically concentrated in valleys, where it is referred to as valley train, or in more unconfined areas as outwash plain deposits. According to Drewry (1986, p 157-66):

> "Most proglacial streams exhibit pronounced changes in regime-glacier-controlled seasonal flow with high periodic discharge of water and sediment. These result in a somewhat unstable environment where there is rapid evolution of channels and in which braiding is characteristic.... Sediments of braided glacial streams are formed principally into a rather complex distribution of incomplete bars and channel fill... Major changes take place in channel pattern and surface elevations produced by strongly contrasting periods of erosion and deposition in response to water and sediment discharge and glacier activity."

There are no extensive outwash deposits in most upland areas in Ohio because there were no major bedrock valleys to provide conduits for the meltwater streams. If it is assumed that sand and gravel interbeds relate to a braided stream environment, as has been postulated for some sites, it means that the ice front had to move back temporarily and, after the deposition of outwash sediments, move forward to ultimately cover them with till. This oscillation of the ice front would need to have happened many times to account for the apparent stacking of sand and gravel deposits that occur in places. In such a hypothetical sequence of events, deposits left after each retreat of the ice front would without doubt have been differentially destroyed, and in part re-entrained in the ice during each subsequent readvance. This would again suggest a series of disconnected rather than areally extensive deposits.

Evidence is strong that such a scenario of repetitive ice retreats and advances, if they occurred, did not produce the sand interbeds at the Franklin County landfill site. In the original investigation, two major till sheets were identified, indicating a temporary retreat and readvance of the glacier. No significant sand and gravel deposits are associated with the contact between the two tills. The original report (Zande and Associates, 1981) states:

> "There are two distinct tills present on this site, with the lower till occurring at a depth of about 50 feet... There is a distinct color change, dark grey to light brown, in sediments at this interface. The lower till is deeply weathered...this indicates a very substantial interval of weathering between the two glacial advances.... There is only a minor accumulation of actual deposits of sand and/or gravel in association with the contact between the two tills."

The absence of significant deposits of sand and gravel outwash on the lower till, plus the survival of a wide-spread weathered zone, clearly show that no proglacial deposits, braided stream or otherwise, were present when the glacier readvanced over this area. The likelihood is remote, therefore, that any of the sand and gravel interbeds within the till were formed in a braided stream environment. The evidence is overwhelming that these stratified interbeds were formed englacially by processes described by Shreve, Drewry, and others.

In a highly technical article, Menzies (1990) speculates on the formation of what he termed sand intraclasts in a "diamicton melange" (essentially a reworked till) in Ontario. Menzies states:

> "One particular sedimentological problem typical of many diamictons (tills) is the presence of incorporated, apparently undeformed lenses or intraclasts of sediment."

Menzies explains his use of the term intraclast as follows:

> "The term intraclast is used...to indicate that these sediments were probably deposited originally within the same depositional basin as the host sediment (till), and following transportation, were fully incorporated within the till... These sediments are poorly consolidated, non-cohesive sands in which original bedding structures, such as cross-stratification often are retained. The effects of removal from the original site of deposition to the newer site of secondary deposition can be deduced from evidence of intraclast tilting and fracturing."

Secondary deposition such as Menzies describes, involving movement of whole blocks of essentially unaltered sand and gravel to positions within the till matrix would account for the isolation of individual sand bodies, their sharp boundaries with the enclosing till, and the lack of tailing off or diminishing trails of stratified material which one might expect with an *in-situ* origin.

It should not be implied from the forgoing discussion that all, or perhaps even most, sand bodies in till are of limited extent and owe their origin to secondary emplacement. Many sand interbeds, from their thickness, known extent, composition, and position within the till are obviously of *in-situ* origin; that is, they were let down along with the till matrix when the ice sheet melted.

In his paper, Menzies described two examples of sand bodies within the till matrix exposed on the outcrop. One was about 18 feet long and 3.5 feet thick; the other was slightly smaller. Menzies states:

> "These...sediments have not suffered secondary deformation *in-situ,* but have probably been moved by a process of erosive fragmentation, entrainment, and emplacement...perhaps because of their confinement or frozen state."

DISCUSSION

The intent of this report is to show the complicated processes associated with deposition of sediments associated with a glacier. Lowell and Brockman (1994), in the guidebook for a field trip for glaciologists in southwest Ohio, list five modes of deposition associated with an advancing glacier and three with a retreating glacier, in addition to three varieties of post-glacial deposition. The authors state:

> "Many attempts have been made to correlate glacial sediments between outcrops on the basis of lithology and other physical properties. These efforts have met with mixed success because of the complexities of the glacial deposition process."

Difficulties in correlation are due in large measure to the breakup of depositional units by subsequent melting of the ice and settling of the till as it loses its water content. Such a degradational break-up would be accompanied by a disordering of the constituent parts, with changes in their orientation, altitude, and lack of continuity between disparate parts of the original deposit. A hypothesis to illustrate the formation and break-up of fairly large sand and gravel deposits formed on till may be visualized as follows:

> Unequal deposition of the till and selective melting out of the glacier left irregular depressions of widely ranging shapes and sizes, into which meltwaters deposited sand, gravel, and silt. The meltwaters overflowed these depressions, leaving their debris loads and emerging beyond the overflow areas carrying little or no sediment, thus leaving a fairly sharp boundary of the granular material. The sand and gravel deposits in the former depressions then may have been broken up and constituent parts shifted during subsequent glacial events, probably involving refreezing, and eventually covered by till. This process of local deposition, disruption of the deposits, and their burial by till happened many times during both the advance and retreat of the glaciers. The sand and gravel beds now occur as isolated or semi-isolated permeable inclusions (seams, lenses, etc.) which have little effect on the general groundwater circulatory system.

These sand bodies cannot be traced laterally with confidence because of the variability of the sediments as shown by differences in closely-spaced wells—including, in some instances, wells in the same cluster. Sand beds in wells scores or hundreds of feet apart cannot be shown to be connected hydraulically even though they may occur at similar depths or elevation, and if water levels in the respective deposits appear roughly accordant.

The tendency in groundwater reports to assume physical and hydraulic continuity between widely-spaced sand beds in wells is illustrated by cross-sections showing a proposed expansion of the landfill. In one cross-section, a sand bed ranging in thickness from less than one foot to about 2.5 feet, and in depth from 44 to 59 feet, and whose position may mark the boundary of an upper and lower till as described in the original report on the landfill, is extended from west to east a distance of nearly 3000 feet on the basis of five wells. The two closest wells are 330 feet apart. and the two most widely spaced wells are nearly 1100 feet apart. Although the continuity of this sand bed, because it lies at the junction of two tills, is plausible, the small number of wells and the large distances between the wells make such a large lateral extension of the bed as a continuous stratum questionable. In fact, on the same cross-section, the sand bed does not appear in a companion well approximately 900 feet beyond the last well in the line of wells in which thin sand is depicted as a continuous bed.

Based on six cross-sections in the landfill expansion report, of a total of 28 wells and borings there are 119 separate sand beds shown, which means that one sand bed is encountered in every 27 feet of drilling More than half of these beds have been extended to adjacent wells on the cross-sections, where they appear to line up with other beds. The average distance between adjacent wells is approximately 1050 feet. The sand beds range in thickness from less than a foot to 30 feet, the latter bed overlying bedrock. Of significance is the fact that one of the thicker beds, 13 feet in one boring, could not be matched to beds in adjacent wells on a west to east section, but was matched to a bed of similar depth in an adjacent well on a north-south section. In this instance, the sand bed appeared to have continuity in a north-south direction but not in an east-west direction. This example of bed orientation and the possibility that many, if not most, of the more extensive sand beds may be linear with a preferred orientation, makes it difficult to draw with confidence areal maps of individual sand beds based on a grid of widely-spaced wells.

Determining the areal distribution of individual sand beds in till is difficult and uncertain without an extensive network of closely-spaced wells, a density of drilling not ordinarily justified by the cost. In general, it can be said that most sand beds probably consist of relatively small inclusions, or lenses, some of which may represent portions of once larger deposits that have been reworked and fragmented by glacial action after their initial deposition. There is no certainty that individual beds are continuous between adjacent wells (unless the wells are exceedingly close together), no matter how perfectly the beds seem to line up in the respective wells.

In sum, the sedimentology of glacial deposition is complex and correlation of individual deposits is difficult. A critical problem in landfill construction in a glaciated terrain relates to the extent and continuity of sand beds in till, commonly referred to as "seams" or "lenses." Of paramount importance in landfill engineering is whether these sand bodies, where they occur in individual wells at roughly accordant levels, represent parts of a wide-spread permeable deposit that might transmit water over large distances, or whether, for the most part, they represent local deposits of relatively small extent of little importance in the groundwater circulatory system.

It is of interest to note a common tendency of hydrogeologists (and geologists) in constructing cross-sections to connect sand bodies from well to well, if they occur somewhat close to the same elevation, even though the wells may be hundreds of feet apart. Other sand bodies in the same well logs that perhaps don't match quite as closely are usually shown as individual lenses, almost always with the well squarely in the middle of a lens-like deposit. In such instances, it is apparent that construction of the cross-sections has been arbitrary and in large part, unjustified by the evidence. One reason for the bias in constructing cross-sections is the lack of closely-spaced wells; that is, wells a few feet or a few tens of feet apart, that may not show continuity over short distances of a fairly thick bed of sand and gravel found in one well but not in a nearby well. It is understood, however, that most cross-sections have been prepared showing a "worst case" scenario for the degree of connectivity of the individual sand lenses. It is also understood that much of this information is "inherited" from past studies, thus restricting the ability to construct a totally new geologic model, and still maintain a high degree of credibility with the landfill permit application.

Few technical papers and texts on glacial geology touch specifically on the origin of sand bodies in till. Glaciologists studying living glaciers seem not to have emphasized this problem, perhaps because of the difficulty in acquiring data in areas away from the ice front. The common practice of extending relatively thin sand beds between wells several tens or even hundreds of feet apart is misleading and conveys what may be a totally erroneous concept of their size and extent.

With respect to the Franklin County Landfill, it is perhaps unfortunate that in the original investigation the essentially random sand beds were classified into specific zones which in themselves suggest a continuity of individual deposits for which, in general, evidence is lacking. Proof of physical and hydraulic continuity in most instances can be achieved only by pumping a given well and monitoring the response, if any, in a nearby well whose connection with the pumped well is unknown.

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